WATER USE IN

CRANBERRY PRODUCTION

SOUTHEASTERN MASSACHUSETTS

WATER USE IN CRANBERRY PRODUCTION

SOUTHEASTERN MASSACHUSETTS

MASSACHUSETTS WATER RESOURCES STUDY

United States Department of Agriculture

Economic Research Service
Forest Service
Soil Conservation Service

February 1975

ABSTRACT

Although agriculture represents a minor component of the Massachusetts economy, the southeastern portion of the state is the major cranberry producing area in the nation. While cranberry production has been increasing in Massachusetts, its share of the national production has been declining in recent years. Over 80 percent of the regions' cranberry production occurs in Plymouth County.

Water management is an integral part of cranberry production. Bogs are flooded over winter to prevent winterkill. In both spring and fall, either flooding or sprinkler systems are utilized periodically to provide frost protection. Water harvesting has become increasingly popular in recent years principally because it increases yields. Flooding is also employed to remove trash and to control certain insects. During dry periods, bogs are also irrigated.

In order to gain an insight as to the interrelationships among cranberry bog acreages by town and selected socioeconomic and locational variables, the factor analysis technique was employed. Five orthogonal factors were extracted through the factor rotation procedure. There were identified as urbanization, cranberry industry viability, accessibility, urbanism, and ruralism.

Using cranberry acreages by town, as the dependent variable, the maximum R^2 improvement regression procedure was employed using sixteen independent variables. By the use of this technique, an R^2 of .984 was determined with as few as five independent variables. Eight multiple regression equations were developed to provide a basis to project future cranberry acreages by town.

Projections based on the regression equation for which data on the

independent variables were most readily available indicated that cranberry acreages would decline 44 percent by 1990. Based on this figure, it was estimated that water use in cranberry production would decline by more than one-half by 1990.

KEY WORDS: water use, cranberry production, Massachusetts, projections, acreages

Water Use in Cranberry Production

Southeastern Massachusetts

Table of Contents

List of Tables

WATER USE IN CRANBERRY PRODUCTION
SOUTHEASTERN MASSACHUSETTS

by

Ronald J. Glass 1/

INTRODUCTION

While agriculture is a minor component of the Massachusetts economy, a relatively small area in the southeastern part of the state produces more cranberries than any other region of the Nation - or the World for that matter. An overwhelming proportion of this production is concentrated in three counties - Plymouth, Barnstable, and Bristol. Actually, almost 85 percent of the state's cranberry production occurs in Plymouth County.

Cranberry growing is of particular interest to water resource planners because water management is an integral part of cranberry culture. Bogs are periodically flooded for several purposes and sprinkler systems have recently found widespread usage for frost protection as well as for other purposes

In the Massachusetts Water Resources Study, the Economic Research Service was assigned the responsibility of estimating present and future water use for agricultural purposes. Since water is used so extensively in cranberry culture, this industry was selected for special study.

PROCEDURE

This report is principally concerned with water use in the growing and harvesting of cranberries and not with the later phases of processing. Much

---

1/ Ronald J. Glass is an Agricultural Economist with the Northeastern Resource Program Group, Economic Research Service, USDA at Upper Darby, Pa.

of the information on cranberry culture, production and trends was provided by the Cranberry Experiment Station at East Wareham, Massachusetts. Current information on cranberry acreages was provided by the Cranberry Marketing Committee located in Wareham, Massachusetts.

Initially, the culture of cranberries with particular emphasis on water use is discussed and estimates of water use for various practices are presented. Trends in cranberry acreages, production and technology are then examined. The marketing of cranberries is described and a brief resume of the marketing agreement is presented.

Since the primary purpose of this report is to project future water use in cranberry production, several techniques are employed to provide the basis for such projections. First, regression analysis techniques are applied to past trends of regional cranberry acreages and yields. Since a more detailed analysis of the factors affecting cranberry acreages is desired, multivariate statistical techniques are applied to selected socioeconomic and locational variables associated with cranberry acreages. By using the town as the basic area for this analysis, it is possible to obtain projections for watershed planning areas by aggregating these towns appropriately. Finally, estimates of water use for various cultural practices are applied to the projected cranberry acreages in order to project water use in cranberry production for 1980 and 1990.

CRANBERRY CULTURE 1/

The origin of cranberry culture can be traced back to the early 1800's on Cape Cod when it was observed that wild cranberry vines responded favorably when sand was blown upon them from nearby dunes. Since then, numerous techniques

---

1/ Much of the information contained in this section was provided by the Cranberry Experiment Station of the University of Mass., located in East Wareham, Mass.

have been developed to increase the productivity of cranberries and to remove some of the inconsistencies of yields from year to year. Water is used in many facets of cranberry management.

Cranberries differ from most commercially produced fruit in several ways. First, they are produced on self-replacing stock and, with proper care, can produce indefinitely. Secondly, cranberries are grown in bogs which puts them at lower elevations than adjacent areas. This makes them especially susceptible to both spring and fall frost damage.1/ Such damages and the uncontrolled water levels in spring are responsible for wide variations in wild cranberry yields from year to year. Such fluctuations are not tolerable in commercial bogs.

Two varieties of cranberries - Early Blacks and Howes - account for approximately 95 percent of the commercial cranberry acreages of southeastern Massachusetts. While both are considered good quality and high yielding varieties, there is roughly twice the acreage of Early Blacks as Howes. One advantage of Early Blacks is that they can be harvested in September or early October so frost damage is less of a threat. It normally requires about three weeks longer for Howes to mature.1/ Since it requires four or five years after planting for cranberry bogs to yield commercial harvests, it is anticipated that these varieties will continue to dominate Massachusetts cranberry production.

In the remainder of this section, some of the cultural techniques employed in commercial cranberry raising will be described. Particular emphasis will be placed on water use as it is related to these techniques. Starting in the winter and proceeding through the seasons until fall, some of the principle cultural measures utilized in cranberry growing are described below.

1/ Cross, Chester, "Flood Management - Massachusetts Cranberry Bogs." Modern Cultural Practice in Cranberry Growing, Publication No. 39, Massachusetts Cooperative Extension Service. and Massachusetts Agricultural Experiment Station, University of Massachusetts., Amherst, Massachusetts., September, 1969.

Winter Flooding

When the ground freezes and the roots are not capable of absorbing sufficient water, the exposed portions of the evergreen cranberry vines tend to give off more moisture than is replaced through the root system. Particularly on windy days, desiccation is apt to occur and many of the exposed portions become what is termed "winterkill" losses. As a means of eliminating such losses, cranberry bogs have traditionally been flooded from early December to early April.

A problem associated with winter flooding is oxygen-deficiency injury. This occurs when snow, or any other substance, prevents the sun from shining through to the cranberry vines. In such cases, photosynthetic activity is halted and oxygen depletion occurs. This diminishes cranberry yields during the subsequent growing season.

More recently, the Cranberry Experiment Station[1/] has recommended shorter flood periods. Their recommendations include postponing initial flooding until the root zone is well frozen and, then, only if weather forecasts indicate "winterkill" conditions. The flood should be removed by the middle of March. If snowfall occurs and the water supply for reflooding is adequate, the flood should be withdrawn. A more shallow flood than had previously been practiced is also recommended. Under these practices, oxygen-deficiency losses can be reduced and yields increased provided adequate care is taken to prevent "winterkill."

Spring Reflow

The spring reflow refers to a flood of several weeks duration which is applied to some bogs after the winter flood has been removed. This flood is usually applied in mid-April and is removed by mid or late May.

1/ Cross, Chester E., "Flood Management - Massachusetts Cranberry Bogs." Modern Cultural Practice in Cranberry Growing, Publication No. 39, Mass. Ag. Exp. Station, Univ. of Mass., Amherst, Mass., Sept. 1969.

There are several advantages to the use of a spring reflow. First, it protects the vines from frost damage. Secondly, bogs subjected to this spring flooding tend to produce higher quality, although fewer, cranberries. Lastly, the spring flood provides a mechanism to retard growth in selected bogs or sections of bogs if diking is adequate so that the fall harvest can be spread over a longer period, thus facilitating the harvest of "just ripe" berries.

Spring Frost Protection

As cranberry buds leave their period of dormancy and begin to expand, they become more and more susceptible to frost damage. Since the seasons's crop is dependent upon the survival of the flower buds, it is imperative that these be protected. By their very nature, cranberry bogs are in low-lying areas and, therefore, apt to suffer from frost damage caused by radiation cooling when surrounding areas are comparatively safe.

The traditional means of affording frost protection, and one that is still used on many bogs, is flooding. A shallow flood, one which provides two inches of water over the soil surface,[1/] is adequate for this purpose but it must be applied before critically low temperatures are reached. Early in the season, frost floods may be retained several nights as a safeguard against potential frost danger. However, once the new growth is underway it is necessary to drain the flood promptly the following morning or face losses in cranberry yield due to "water damage." [2/]

In recent years, low gallonage sprinkler systems have received wide usage as a means of protecting cranberry bogs from frost. This technique, which depends upon the heat of fusion, has several advantages over the traditional

---

1/ Peterson, B.S., Cross, C.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin No. 201, Massachusetts Department of Agriculture - Division of Markets, Boston, Mass., June 1968.

2/ Cross, Chester E., "Flood Management - Massachusetts Cranberry Bogs." Modern Cultural Practice in Cranberry Growing, Publication No. 39, Mass. Ag. Exp. Station, Univ. of Mass., Amherst, Mass., September 1969.

frost flooding. As their name implies, sprinkler systems utilize far less water to provide frost protection than does flooding. Sprinkler systems also provide instantaneous protection when started so the decision to provide protection can be postponed until temperatures approach the danger point. When frost protection floods are used, the decision on application must be made hours before the occurrence of dangerous temperatures in order to insure adequate protection. If temperatures do not fall to the dangerous level water and other resources have been wasted and water damage to the vines may occur. On the other hand, failure to start the flood in time can result in serious crop losses due to frost damage.

Irrigation

Sprinkler systems installed for frost protection provide an efficient means for summer irrigation. They are also useful in the spreading of fertilizers and pesticides.

In bogs in which sprinkler systems have not been installed, the older method of irrigation by flooding is still employed. Since many bogs are uneven, it is often necessary to submerge some vines in order to reach others. When vines are with flowers or newly set fruit, losses are apt to occur if they are submerged over three hours.[1/]

Fall Frost Protection

As is the case with the tender new growth of the spring, it is necessary to protect the ripening berries from frost in the fall. Here again, many of the same advantages of sprinkler systems apply. In addition, dry harvesting is often possible the afternoon following the application of the sprinkler but not so if the bog was flooded. Frequent floodings are also likely to reduce the storing qualities of the cranberries.

1/ Cross, Chester E., "Flood Management - Massachusetts Cranberry Bogs." Modern Cultural Practice in Cranberry Growing, Publication No. 39, Massachusetts Agricultural Experiment Station, University of Massachusetts, Amherst, Massachusetts, Sept., 1969.

Harvesting

Cranberries are either dry harvested or flood harvested. In dry harvesting, there is a 20 to 25 percent loss of berries in the picking process. Damage to vines is another problem associated with dry harvesting. One of the biggest advantages of this method is that the berries retain a better keeping quality and, thus, are better adapted to fresh markets. A premium for dry picked berries is often paid for this reason.

Flood harvesting takes advantage of the fact that cranberries float in water. After a bog is flooded, the berries are mechanically detached from the vines and float to the surface. The fruit is moved to the shore, skimmed off, and loaded on trucks. Cranberries harvested in this manner are used only for processing. The chief advantages of water harvesting are stated by Peterson et al [1/] as "research has shown a 20% increase in harvest efficiency by picking in flood water and a similar increase in future crops, an increase attributed to the greatly reduced mechanical damage to cranberry vines by machines which skim the floating berries from the tips of flooded vines."

Trash Floods

When dry picking methods have been employed, the bog is often flooded shortly afterwards as a means of eliminating debris. Such materials as dead leaves, broken twigs, and berries that have been missed float to the surface and can be skimmed off. If this flooding is undertaken immediately after a dry harvest, it can be an effective means of reducing damage to vines that have been mechanically injured.

1/ Peterson, B.S., Cross, C.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin No. 201, Massachusetts Department of Agriculture - Division of Markets, Boston, Mass., June 1968.

Sanding

Resanding may have been the first cultural practice applied to cranberry bogs. Resanding is "a cultural practice whereby a thin layer of sand is spread over the surface of mature cranberry bogs." 1/ This layer of sand, which varies from 1/4 to 1 inch in depth, has several beneficial effects on the plants which generally results in increased vigor, growth and yield. Bogs are most frequently resanded every three to five years. While several methods including spreading the sand on the ice of the winter flood had been previously employed, today most resanding is accomplished by machines specifically designed for this task.

QUANTITY OF WATER USED

There are several factors which make it rather difficult to estimate the quantity of water that is likely to be utilized during a given season for cranberry production. The number of occurrences of critical weather conditions is largely unpredictable for specific years although average patterns can be useful when considering the general situation. While it is understood that many cranberry bogs in Massachusetts are seriously out of grade, necessitating excessive amounts of water to flood these areas sufficiently to protect the higher elevations, there is little specific information on the extent of these. Finally, an unspecified number of bogs have pumping facilities which enable them to return water to their reservoirs after flooding.

Estimates of water use on a typical 10-acre level bog and 10-acre bog with a two-foot difference in grade were prepared by the Cranberry Experiment Station 2/ (Table 1). These estimates indicate that the uneven bog requires more than

---

1/ Demoranville, I.E., "Resanding Cranberry Bogs," Modern Cultural Practice in Cranberry Growing, Publication No. 39, Mass. Ag. Exp. Station, Univ. of Mass., Amherst, Mass., Sept. 1969.

2/ Norton, John S., "Development of Methods for increasing the Efficiency of Water Use in Cranberries," Proceedings of the Water Resources Research Symposium, Publication No. 3, Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts, June 2, 1967.

Sanding

Sanding may have been the first cultural practice applied to cultivated bogs. [illegible] to a cultural practice whereby a thin layer of sand is spread over the surface of mature cranberry bogs." This layer of sand, which varies from 1/4 to 1 inch in depth, has [illegible] effects on the plants [illegible] generally results in increased vigor, growth and yield. [illegible] recommended [illegible] three to five years. While several methods [illegible] the sand [illegible] ice of the winter flood had been previously employed [illegible] is accomplished by machines specifically designed for [illegible]

QUANTITY OF WATER [illegible]

There are several factors which make it rather difficult to estimate quantity of water that is likely to be utilized during a given season for cranberry production. The number of occurrences of critical weather conditions is largely unpredictable for specific years although average patterns can be useful when considering the general situation. [illegible] of many cranberry bogs in Massachusetts are extremely out of grade, necessitating excessive [illegible] of water to flood [illegible] areas sufficiently to protect the higher elevations. [illegible] is little specific information on the extent of these. Finally, an unspecified [illegible] of bogs have pumping facilities which enable them to return water to their reservoirs after flooding.

Estimates of water use on a typical 10-acre level bog and 10-acre bog with a two-[illegible] in grade were prepared by the Cranberry Experiment Station [illegible]

[illegible] that the uneven bog requires more [illegible]

twice as much water annually for the various cultural activities requiring flooding. In both cases, floodings for spring frost protection was the greatest user of water. The uneven bog required 30 million gallons annually for spring frost protection as compared to 10 million gallons for the even bog. Besides the obvious need of additional water to offer complete frost protection of uneven bogs, it is necessary to start flooding earlier to insure protection since more water is involved. This makes it necessary to base the decision on whether or not to flood on weather forecasts available earlier in the day. These are less reliable and more likely to induce a bog operator to flood for protection when later forecasts indicate conditions unlikely for frost damage.

Table 1: Typical Annual Water Use by Flooding on (1) a Ten Acre Level Bog and (2) A Ten-Acre Bog with a Two-Foot Difference in Grade. (Uniform Slope) 1/

Flooding Purpose		Type of Bog Level	Out-of-Grade
		- - - Million of Gallons	- - - - -
Winter flood, two floodings		7	14
Late water 2/		5	8
Spring frost, six floodings		10	30
Fall frost, four floodings		7	13
Water harvest		2	5
Clean-up flood		4	7
	Total	35 or 106 Acre-Feet	77 or 239 Acre-Feet

1/ Norton, John S., "Development of Methods for increasing the Efficiency of Water Use in Cranberries," Proceedings of the Water Resources Research Symposium, Publication No. 3, Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts, June 2, 1967.

2/ When late water is used spring frosts will usually not exceed three in number

Regardless of grade, the installation of sprinkler systems to provide frost protection has the potential for reducing water use in cranberry production. Since sprinklers afford almost immediate protection, there is no need to begin hours before anticipated critical temperatures in order to assure adequate protection. Sprinkler systems also use far less water than flooding; an average application of about one-half inch of water being sufficient to provide a night's protection.

Individual flooding areas in southeastern Massachusetts vary in size from less than an acre to over 50 acres. Since the ideal size for water harvesting is usually two to four acres, many larger flooding areas have been diked into smaller units. Where uneven bogs are subdivided into smaller flooding areas, less water is required to flood for obvious reasons.

TRENDS IN CRANBERRY PRODUCTION

Massachusetts has long been the leading cranberry producing state in the Nation. In 1900, almost two-thirds of the Nation's total production originated in the Commonwealth (Table 2). Although production has increased substantially to over one million barrels in 1971, the proportion of total cranberry production from Massachusetts has declined since the turn of the century. In 1972, Massachusetts accounted for about 37 percent of the Nation's cranberry production.

Cranberry production per acre has also increased considerably in Massachusetts since 1900. In that year, average production was near 18 barrels per acre compared to 96 barrels per acre in 1971. During the first half of the twentieth century, Massachusetts exceeded the National average in cranberry production on a per acre basis; however, since then the National average has exceeded the state's. This can be partially attributed to the fact that more recently built bogs, which predominate many other areas, are more level, and thus, more adaptable to flood harvesting. The wide fluctuations in cranberry

protect [illegible] control for reducing [illegible] in cranberry bogs

[illegible] these conditions called almost [illegible] protection. [illegible] to begin before nightly [illegible] temperature [illegible] protection. Sprinkler systems also can [illegible] an average application of about [illegible] inch of water being sufficient to provide a night's protection.

[illegible] flooding areas in southeastern Massachusetts vary in size from less than an acre to over [illegible] acres. Since the ideal size for water movement is usually two to four acres, many larger flooding areas have been [illegible] smaller units. These [illegible] subdivided into smaller flooding [illegible] water is required [illegible] various reasons.

TRENDS IN CRANBERRY PRODUCTION

Massachusetts has long been the leading cranberry producing state in the Nation. In 1900, almost two thirds of the Nation's total production originated in the Commonwealth (Table 2). Although production has increased substantially to over two million barrels in 1971, the proportion of total cranberry production from Massachusetts has declined since the turn of the century. In 1972, Massachusetts accounted for about [illegible] percent of the Nation's cranberry production.

Cranberry production per acre has also increased considerably in Massachusetts since 1900. [illegible] that year, average production was near [illegible] barrels [illegible] were compared to [illegible] barrels per acre in 1971. During the [illegible] half of the [illegible] Massachusetts [illegible] in cranberry

Table 2 Historic trends in cranberry production, yields and acreage for Massachusetts and the United States, selected years, 1900 to 1972. 1/

	Massachusetts			United States		
Year	Acres	Production 1,000Barrels	Yield per Acre-Barrels	Acres	Production 1,000Barrels	Yield per Acre-Barrels
1900	11,300	200	17.7	21,500	318	14.8
1910	14,000	312	22.3	25,900	369	22.0
1920	14,000	309	22.1	27,000	472	17.5
1930	13,800	395	28.6	27,640	583.5	21.1
1940	13,900	322	23.2	25,540	570.5	22.4
1950	14,800	610	41.2	26,390	982.7	37.2
1955	13,400	546	40.7	22,270	1,025.8	46.1
1960	12,700	805	63.4	21,140	1,340.7	63.4
1965	11,400	735	64.5	20,640	1,436.8	66.0
1966	11,400	768	67.4	20,760	1,598.6	77.0
1967	11,400	573	50.3	21,120	1,424.3	67.4
1968	11,000	660	60.0	21,135	1,467.8	69.4
1969	11,100	755	68.0	21,185	1,823.1	86.1
1970	10,900	957	87.8	21,445	2,087.1	97.3
1971	11,000	1,072	96.2	22,310	2,264.8	101.5
1972	10,900	820	75.2	22,290	2,078.0	93.2

1/ Figures from 1900 to 1967 were taken from: Petersen, B.S., Cross, G.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin 201, Massachusetts Department of Agriculture, Division of Markets, June 1968.

Figures from 1968 to 1972 were obtained from the New England Crop Reporting Service of the United States Department of Agriculture - Statistical Reporting Service, Boston, Mass.

productivity can be attributed largely to variations in weather conditions from year to year.

Total acreages of cranberry bogs in Massachusetts have been slowly declining since 1950, but the state still accounts for nearly one-half of the National total. The total acreage of bogs in the State in 1973 was 11,266.[1/]

While commercial cranberry bogs were once widely distributed throughout most of the Commonwealth, they have become more and more concentrated in the southeastern section in recent years. Plymouth County presently contains about 81 percent of the state's total acreage of cranberry bogs. Barnstable County, once the leader, and Bristol County account for most of the remainder.

With respect to the planning areas defined by the Massachusetts Water Resources Study,[2/] Buzzard's Bay contains nearly one-half of the state's total acreage (Table 3). The Taunton and South Shore Planning Areas contain most of the remainder. Cape Cod and the Islands, once the leading cranberry producing area in the State, had less than 1,500 acres of commercial bogs in 1973. A few scattered bogs are still found in some other eastern Massachusetts Planning Areas.

In 1973, there were 46 towns in Massachusetts having commercial cranberry bogs (Table 4). Carver led all other towns with 2,585 acres of bogs. The top eight towns were all located in Plymouth County and accounted for 71 percent of the state's total cranberry acreage.

1/ Cranberry Marketing Committee, Wareham, Massachusetts

2/ See Appendix A for a list of towns included in each planning area.

productivity can be attributed largely to exceptions in weather conditions from year to year.

Total acreages of cranberry bogs in Massachusetts have been slowly declining since 1948, but the state still accounts for nearly one-half of the National total. The total acreage of bogs in the State in 1973 was 11,300.[1]

While commercial cranberry bogs were once widely distributed throughout much of the Commonwealth, they have become more and more concentrated in the southeastern section in recent years. Plymouth County presently contains about 71 percent of the state's total acreage of cranberry bogs. Barnstable County, once the leader, and Bristol County account for most of the remainder.

With respect to the planning areas defined by the [illegible] Resources Study,[2] Buzzard's Bay contains nearly one-half of the state's total acreage (Table 9). The Taunton and South Shore Planning Areas [illegible] of [illegible] Cape Cod and the Islands, once the leading cranberry producing area in the State, had less than 1,500 acres of commercial bogs in 1973. A few scattered bogs are still found in some other eastern Massachusetts Planning Areas.

In 1973, there were 46 towns in Massachusetts having commercial cranberry bogs (Table 10). Carver led all [illegible] with [illegible],385 acres of bogs. The top

Table 3. Acres of Cranberry Bogs by watershed planning areas,1/ selected years, 1946 to 1973

Year	Buzzards Bay	Watershed Taunton	Planning South Shore	Areas Cape Cod, & Islands	Other
			Acres		
1973 2/	5,431	2,097	2,159	1,468	111
1966 3/	5,539	2,139	2,303	2,211	77
1956 3/	5,780	2,065	2,669	2,787	175
1946 3/	5,861	2,495	2,623	3,703	257

1/ See Appendix A for list of towns included in each planning area.

2/ Information obtained from the Cranberry Marketing Committee, Wareham, Mass.

3/ Peterson, B.S., Cross, C.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin 201, Massachusetts Department of Agriculture, Division of Markets, June 1968.

Table 4. Acres of cranberry bogs by town for Massachusetts, selected years, 1946 to 1973

	Acres of Cranberry Bogs			
	1973[1/]	1966[2/]	1956[2/]	1946[2/]
	- - - - - - - - - - - - Acres - - - - - - - - - - - -			
Carver	2,585	2,845	2,918	2,916
Wareham	1,642	1,540	1,656	1,868
Plymouth	1,242	1,212	1,360	1,252
Rochester	889	853	920	838
Middleboro	759	790	653	855
Pembroke	326	366	318	384
Duxbury	305	369	493	481
Halifax	287	293	297	276
Freetown	265	212	198	218
Barnstable	263	367	397	506
Plympton	233	268	222	269
Harwich	211	340	401	498
Mashpee	209	243	248	330
Yarmouth	209	217	255	317
Kingston	200	255	261	220
Hanson	183	192	226	332
Lakeville	166	136	159	212
Marion	154	164	146	120
Nantucket	145	290	278	292
Falmouth	110	199	211	223
Bourne	98	140	162	268
Sandwich	94	133	177	167
Easton	78	45	48	43
Mattapuisett	63	67	84	77
Taunton	62	56	129	140
Brewster	61	111	243	352
Acushnet	52	53	50	29
Norton	46	88	80	105
Marshfield	45	50	161	220
Dartmouth	34	6	5	--
Dennis	26	93	157	377
Scituate	23	25	26	26
Chatham	21	30	80	131
Orleans	21	18	79	127
Wrentham	21	21	31	--
Sharon	20	18	20	16
Carlisle	19	0	39	39
Chelmsford	19	0	0	10
E. Bridgewater	14	15	12	19
Norwell	13	15	16	10
New Bedford	12	11	1	13
Raynham	10	10	18	15
Wilmington	10	3	9	10
Foxboro	8	22	13	7
Norfolk	8	12	--	--
Hanover	5	11	34	30

1/ Figures obtained from Cranberry Marketing Committee, Wareham, Mass.

2/ Petersen, B.S., Cross, C.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin 201, Mass. Dept. of Agriculture, Division of Markets, June 1968

Besides the trend for increased production on fewer acres, there have also been changes in the ownership patterns and production techniques in the cranberry industry. The tendency has been toward fewer, but larger producers. From 1946 to 1966, the average acreage of cranberry bog per grower increased from 12.3 to 18.2.1/ In all, there were 571 cranberry growers during the 1973 season in southeastern Massachusetts but many of these are part-time operators, most of which harvest five acres or less. These may be contrasted to the largest operating unit which has over 1,500 acres.

One notable change in cranberry production in recent years has been the increased use of sprinkler systems for frost protection and irrigation. From 1962 to 1966, acreages with sprinkler installations increased from less than 50 to 2,238.1/ In 1973, estimates by the Cranberry Experiment Station indicated that there were about 7,500 acres of bog with sprinkler systems. Due to the number of bogs with exceptionally good water supplies on which the installation of sprinkler systems would not be justified, the Experiment Station estimates that the proportion of bogs with sprinkler systems installations will not exceed 80 to 85 percent of total acreage.

Another recent change in the cranberry industry in Massachusetts has been the rapid increase of water harvesting. In 1968, only about seven percent of total cranberry production had been harvested in this manner. This more than doubled the following year and has been increasing substantially since then. For 1973, it was estimated that about one-quarter of the total cranberry acreage and 40 percent of all production in the state was water harvested. It is estimated that about two-thirds of the present cranberry acreage has the physical

---

1/ Petersen, B.S., Cross, C.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin 201, Massachusetts Department of Agriculture, Division of Markets, June 1968.

[illegible] been [illegible]

cranberry industry. The tendency has been toward fewer, but larger producers. From 1966 to 1968, the average acreage of cranberry bog per grower [illegible] from [illegible] to 18.3.[illegible] In all, there were 511 cranberry growers during the 1970 season in southeastern Massachusetts but many of these are part-time operators, most of which manage five acres or less. These may be contrasted to the largest operation [illegible] which has over 1,300 acres.

[illegible] change in cranberry production in recent years has been the development of sprinkler systems for frost protection and irrigation. [illegible] [illegible] 1968 [illegible] sprinkler installations increased from less than [illegible] to 2,238.[illegible] In 1973, estimates by the Cranberry Experiment Station [illegible] [illegible] [illegible] one-half [illegible] of bog with sprinkler systems. [illegible] [illegible] of bogs with exceptionally good water supplies on which the installation of sprinkler systems could not be justified, the Experiment Station [illegible] that the proportion of bogs with sprinkler systems installations will [illegible] about 85 percent of total acreage.

Another recent change in the cranberry industry in Massachusetts has been [illegible] rapid increase in water harvesting. In 1968, only about seven percent of total cranberry [illegible] acreage had been harvested in this manner. This more than doubled the following year a[illegible] increasing substantially since then. [illegible] 1972, it [illegible] estimated that [illegible] one-quarter of the total cranberry acreage and 27 percent of all production [illegible] the sta[illegible]

estimated that [illegible] -[illegible] the pres[illegible]

[illegible]

11

capability to be water harvested - out of grade bogs and insufficient water supplies being the principle limiting factors on the remaining one-third.[1/]

Besides the physical limitations of some cranberry bogs, there are a number of other factors which are likely to influence the proportion of future acreages that are water picked. Since more labor is needed for dry picking, the availability of suitable seasonal workers will certainly be a determining factor. The magnitude of the price differential paid for dry-picked berries will also be a major consideration - this differential must at least compensate for quantity losses and the additional labor costs associated with dry picking to make it attractive to growers. There is also some speculation that a drying operation will be constructed in the area, thus, enabling water-picked berries to sold as fresh fruit. It is also suggested that bogs not adaptable to water picking are the most likely to drop out of production in future years.[2/]

CRANBERRY MARKETING

Massachusetts cranberries are produced for two somewhat distinct market outlets - one for the sale of fresh fruit and the other for processing. Because cranberries are perishable; the fresh fruit market only extends through the fall and early winter. In this area cranberries destined to be sold fresh should be dry picked in order to retain better storing qualities. Losses and deterioration of fresh cranberries can be reduced substantially by refrigeration.

Most of the cranberries produced in Massachusetts are sold for processing (Table 5). In five of the past seven years, over 70 percent of the cranberries marketed were sold for processing. In 1972, fresh sales were at their

---

1/ Estimates provided by the Cranberry Experiment Station, University of Massachusetts, East Wareham, Massachusetts.

2/ Cranberry Marketing Committee, Wareham, Massachusetts.

3/ Beattie, J.R. and Demoranville, I.E., A Fresh Cranberry Market Survey, Bulletin No. 501, Cranberry Experiment Station, University of Massachusetts, Wareham, Massachusetts.

lowest in six years while sales for processing were their second highest since 1964. Cranberries designated for processing may be water harvested and shipped in bulk to the plants. They are either frozen or processed within a few days of arrival to minimize deterioration losses. In order to provide an incentive to growers to harvest fruit suitable for the fresh market, a premium is paid for dry-picked cranberries. A smaller incentive payment is given for vine-ripened "blending" berries which are used in juice production.

Most of the cranberries produced in southeastern Massachusetts are sent to the Ocean Spray growers' cooperative plants located within the area. The cooperative has been quite active in developing and promoting new cranberry products over a period of time when national production has increased considerably.

Since 1965 the total value of cranberries marketed in southeastern Massachusetts has fallen below $10 million only once (Table 5). The 1971 crop was valued at $11,571,000. Cranberry prices per barrel have also been consistent in recent years. From 1965 to 1971, the season average price per barrel exceeded $15.00 five times. The lowest price over this period was $11.90 in 1970.

In 1968, growers across the nation voted overwhelmingly in favor of a marketing order and agreement to limit cranberry production.[1/] An allotment program was set up based upon cranberry acreages in production or planted by August 16, 1968. Individual marketing quotas are to be based upon the average of a growers two best crops during the base period, the six crop years from 1968 to 1973. The Cranberry Marketing Committee was set up to administer this program.

The Committee has the responsibility of determining the market allotment

---

1/ United States Department of Agriculture, Consumer and Marketing Service, Part 929, as amended August 16, 1968.

[illegible] little going for [illegible] their normal channels [illegible] designated for processing may be moved [illegible]

[illegible] plants. They are either [illegible] by processors [illegible] a few [illegible] cooperative [illegible]. In order to provide [illegible] growers to harvest fruit suitable [illegible] the fresh market, [illegible] is paid on [illegible] cranberries. A similar [illegible] payment is given [illegible] [illegible] berries which are used in juice production.

Most [illegible] processed in [illegible] the [illegible] Spray growers' cooperative plants located [illegible]. The [illegible] has been [illegible] in developing and promoting [illegible] products [illegible] a percent of the [illegible] national production [illegible]

[illegible] total value of cranberries marketed [illegible] has fallen [illegible] \$10 million only once (Table [illegible]). [illegible] was valued at \$11,571,000. Cranberry prices per barrel have [illegible] in recent years. From 1968 to 1971, the [illegible] average price per barrel exceeded \$15.00 five times. The lowest price over [illegible] was [illegible] in 1970.

In 1968, growers across the nation voted overwhelmingly in favor of a [illegible] order and agreement to limit cranberry production.[1] An allotment [illegible] was set by based upon cranberry acreage in production or planted by [illegible] individual members [illegible] are to be based upon the average [illegible] best crops during the base period, the eligible [illegible] [illegible] 1971. [illegible] Cranberry Marketing Board [illegible] set up to administer this

TABLE 5: Distribution of Cranberry Sales Between Fresh and Processing Market and Value of Sales 1/

YEAR	TOTAL PRODUCTION 2/	TOTAL SALES	FRESH SALES QUANTITY	FRESH SALES PERCENT OF TOTAL	SOLD FOR PROCESSING QUANTITY	SOLD FOR PROCESSING PERCENT OF TOTAL	SEASON AVERAGE PRICE PER BARREL 3	TOTAL VALUE
	1,000 barrels	1,000 barrels	1,000 barrels	Percent	1,000 Barrels	Percent	Dollars	1,000 Dols.
1964	660	603	249	41.3	354	58.7	14.40	9,504
1965	735	671	234	34.9	437	65.1	15.60	11,456
1966	768	713	197	27.6	516	72.4	15.20	11,674
1967	573	503	146	29.0	357	71.0	14.90	8,538
1968	660	622	201	32.3	421	67.7	15.40	10,164
1969	755	749	182	24.3	567	75.7	15.40	11,627
1970	957	817	210	25.7	607	74.3	11.90	10,282
1971	1,072	671	230	35.1	441	64.9	15.70	11,571
1972	820	770	170 4/	22.1	600 4/	77.9		

1/ Massachusetts Agricultural Statistics, compiled by the New England Crop and Livestock Reporting Service, USDA - Statistical Reporting Service, Boston, Massachusetts, June 1973.

2/ Difference between production and the totals of fresh sales and sales for processing are economic abandonment.

3/ Equivalent return at first delivery point, screened basis.

4/ Cranberries, compiled by New England Crop Reporting Service, U.S. and Massachusetts Departments of Agriculture Cooperating, November 14, 1973.

for each grower in the United States. This will be accomplished, by first determining the total marketable quantity for a given crop year. The marketable quantity is to be apportioned among the growers on the basis of their individual base quantities, which are determined by multiplying a grower's established cranberry acreage as of February 1, 1974, by the average sales per acre for the top two years of the base period. An allotment percentage, which is determined by dividing the marketable quantity by the total for each grower's base quantities, will be applied to individual base quantities to determine a grower's market allotment.

TIME SERIES ANALYSIS

Regression analysis of time series data was employed as a means of identifying trends in cranberry acreages and yields per acre for the time period from 1950 to 1972. Both curvilinear and linear regressions were used in order to provide a basis for alternative projections based upon time series information alone. The available information on acreages and yields was for the entire southeastern Massachusetts cranberry growing region so no attempt was made to develop projections by planning areas during this phase of the analysis.

Cranberry Acreages

The linear regression equation for cranberry acreage over time was:

$$Y = 235.8 - 1.8\ t$$

where

Y = acres of cranberry bogs X 100

t = year (1950 = 1)

This equation has a coefficient of determination (R^2) of .957.

The estimating equation for the curvilinear regression was:

$$\log Y = 4.97799 - 0.01459\ t$$

with Y and t defined as indicated above. For this equation, the coefficient of determination was slightly higher (.967) than is the case of the linear equation described above.

Yields per Acre

Linear and curvilinear regressions were also run on cranberry yield in barrels per acre. The linear regression equation was:

$$Y = 32.0 + 2.1\ t$$

where

Y = yield of cranberries per acre (barrels)

t = year (1950 = 1)

The coefficient of determination for this equation was .683.

For the curvilinear regression, the estimating equation was:

$$\log Y = 3.55241 + .03694\ t$$

with Y and t defined as indicated for the previous equation. This estimating equation had a slightly higher coefficient of determination (.697) than did the linear regression.

MULTIVARIATE ANALYSIS

Rather than merely extrapolating past trends as a means of projecting future cranberry acreages in southeastern Massachusetts, it was decided to examine the effects of selected socio-economic and locational variables relative to their relationships with cranberry acreages. This approach appears to have two distinct advantages: (1) It provides an opportunity to assess the effects of resource competition on the quantity of land devoted to cranberry culture and, thus, a more meaningful basis for projecting. (2) Since the relevant socio-economic data are avialable by towns, it makes it possible to project acreages on this basis and aggregate the towns into watershed planning ares.

Initially, twenty-three variables indicative of various aspects of resource competition were selected for analysis (Table 6). Subsequently, six of these

Table 6: Variables included in multivariate analysis for Massachusetts cranberry study

Variable Number	Description of variable
X_1	Acres of cranberry bogs in town, 1973 1/
X_2	Acres of cranberry bogs in town, 1966 2/
X_3*	Town population, 1970 3/
X_4	Change in town population, 1960 to 1970 3/
X_5	Population density for town, 1970 4/
X_6	Change in population density of town, 1960 to 1970 4/
X_7	Acres of land suitable for development within town 4/
X_8*	Property tax per $1,000 real assessment for town, 1971 5/
X_9	Property tax per $1,000 real assessment for town, 1972 5/
X_{10}*	Miles of road in town 4/
X_{11}	Unemployment rate for town, 1970 4/
X_{12}	Distance from center of town to nearest cranberry market center 6/
X_{13}	Average annual wage for town, 1971 4/
X_{14}	Distance from town center to Boston 4/
X_{15}	Peak hour transportation time from town to Boston, 1970 4/
X_{16}*	Size of town in acres 4/
X_{17}	Median family income for town 4/
X_{18}	Acres of town in urban category, 1972 4/
X_{19}	Percent of town in urban category, 1970 4/
X_{20}	Change in acreage of town in urban category, 1952 to 1972 4/
X_{21}*	Total housing units occupied
X_{22}*	Total housing units in town, 1970 4/
X_{23}	Change in total housing units in town, 1960 to 1970 4/

*Variables removed from further consideration due to high intercorrelation with other variables retained for analysis.

1/ Cranberry Marketing Committee, Wareham, Massachusetts

2/ Peterson, B.S., Cross, C.E., and Tilden, N., The Cranberry Industry in Massachusetts, Bulletin 201, Massachusetts Department of Agriculture, Division of Markets, June, 1968.

3/ 1970 Census of Population, Massachusetts, U.S. Dept. of Commerce, Bureau of Census, June 1971.

4/ Empiric Data File, Southeastern New England Study of Water and Related Land Resources, USDA- Economic Research Service, Upper Darby, Pa.

5/ Massachusetts Federation of Taxpayers Association

6/ Office Computations

were removed from further consideration due to high inter-correlations with other variables. In cases where the correlation coefficient (R) between variables equaled or exceeded .90, one of the variables was removed from further consideration. After completing this process, seventeen variables were retained for analysis.

In order to gain a better insight as to the interrelationships that exist among the variables included in this phase of the study, the factor analysis[1/] technique was employed. This technique makes it possible to attain a parsimonious description of the observed data in terms of a limited number of functional entities which are called factors. While eliminating the bias associated with designating variables as dependent or independent, this method of analysis relies on subjectivity to select the final loadings retained under each factor and to identify these factors. The factor analysis technique also provides a means of eliminating additional variables not strongly associated with any of the factors.

Since a primary objective of this study was to project cranberry bog acreages so that estimates of future water use in cranberry production can be made, multiple regression techniques were also employed. Initially, a maximum R^2 improvement step-wise multiple regression technique [2/] was utilized in order to attain the highest possible coefficient of determination with a limited number of variables. Individual regressions were also run using various combinations of selected variables. This was undertaken to provide alternative projection equations; these being useful depending on data availability. While

---

1/ A detailed discussion of this methodology may be found in Multivariate Procedures For The Behavorial Sciences, by William W. Couley and Paul R. Lohnes, John Wiley and Sons, New York, 1962.
2/ Service, Jolayne, A User's Guide to Statistical Analysis, Dept. of Statistics, North Carolina State Univ., Raleigh, N.C., August 1972, p. 128.

the interpretative shortcomings of using these means to develop regression equations and the difficulties associated with extending regression equations beyond the scope of the data are realized, this approach provides a feasible means of projection. Inherent in these projections is the assumption that current interrelationships among variables will continue to exist in the future. The regression equations so developed will be utilized solely for projective purposes since their validity for interpretative purposes is dubious.

Factor Analysis

With the criterion set that only those factors have eigenvalues of 1.00 or greater are to be retained, five orthogonal factors are extracted from the seventeen variables through the factor rotating procedure. This procedure maximizes the difference between the selected factors while minimizing the differences within them. The five orthogonal factors explain the maximum variance for the individual variables considered collectively.

There are several ways in which the resultant factor matrix may be examined (Table 7). For this study, the columns are examined to determine the composition of the derived factors and unimportant relationships are eliminated. Since loadings are derived for all seventeen variables, the elimination of unimportant relationships and the selection of final factor loadings is based on significance tests with α = .001 and 37 degrees of freedom 1/.

The most subjective task associated with factor analysis is the interpretation of the final factor loadings. In the following subsections, an attempt

1/ Biometrika Tables for Statisticians, Volume I, edited by E. S. Pearson and H. O. Hartley, Cambridge University Press, 1954, pg. 146.

Table 7. Rotated factor matrix[1/]

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
X_1	-0.02762	(0.97654)	0.06122	-0.09277	0.09664
X_2	0.02390	(0.97087)	0.00745	-0.09806	0.10211
X_4	(0.75930)	-0.05281	0.11092	0.12975	(-0.51770)
X_5	0.00601	-0.08857	0.11706	(0.92320)	0.00262
X_6	(0.53716)	-0.04371	0.04267	0.07006	(-0.72205)
X_7	0.45983	0.43076	0.25321	-0.29784	0.51174
X_9	-0.05457	0.07646	(0.74064)	(0.52333)	-0.06890
X_{11}	0.01853	0.17921	0.13496	0.04175	0.45499
X_{12}	0.05581	-0.35513	(-0.67628)	-0.05236	-0.34763
X_{13}	0.05552	0.04890	0.12635	0.12271	(-0.54422)
X_{14}	-0.02224	-0.04878	(-0.82714)	-0.15104	0.44533
X_{15}	-0.07293	0.04991	(-0.63803)	0.09307	-0.01532
X_{17}	-0.02528	-0.23897	0.47643	-0.13825	(-0.60620)
X_{18}	(0.79478)	0.09209	0.04368	0.43099	0.27584
X_{19}	0.33162	-0.17039	-0.03368	(0.86750)	-0.16301
X_{20}	(0.91695)	0.10403	-0.00446	-0.00595	0.08805
X_{23}	(0.80147)	-0.14183	-0.07307	0.02955	-0.31225

1/ Parentheses about loadings indicate statistical significance at = .001 and 37 degrees of freedom.

is made to identify and interpret these factors in a meaningful manner.

Factor 1: Urbanization. Since this factor has the highest eigenvalue, it emerges as the most important. Significant loadings are found for five of the seventeen variables for this factor. These are, in order of absolute magnitude, as follows:

X_{20}	Change in acreage of town in urban category, 1952 to 1972	0.91695
X_{23}	Change in total housing units in town, 1960 to 1970	0.80147
X_{18}	Acres of town in urban category, 1972	0.79478
X_4	Change in town population, 1960 to 1970	0.75930
X_6	Change in population density of town, 1960 to 1970	0.53716

Urbanization is the process of which rural acres become urban. It is noteworthy that four of the five loadings retained under this factor are indicative of change. Obviously, a positive change in the town acreage in the urban category over time (X_{20}) is indicative of urbanization. Likewise, changes in total housing units (X_{23}), town population (X_4), and the population density(X_6) are positively related to urbanization. Another measure of the degree of urbanization is the acres in the urban category at a given point in time (X_{18}).

Factor 2: Cranberry Industry Viability.

Two significant loadings are found among the variables for this factor. These are:

X_1	Acres of cranberry bog in town, 1973	0.97654
X_2	Acres of cranberry bog in town, 1966	0.97087

The acres of active cranberry bogs for 1973 (X_1) and for 1966 (X_2) are positively related to the viability of the cranberry industry. Acreages by towns for the two time periods are expected to be closely related because of the

time required to establish commercial bogs and the marketing agreement prohibiting the development of new bogs after August 16, 1968.

Factor 3: Accessibility.

There are four significant loadings for this factor. These are:

X_{14}	Distance from town center to Boston	-0.82714
X_9	Property tax per $1,000 real assessment for town, 1972	0.74064
X_{12}	Distance from center of town to nearest cranberry market center	-0.67628
X_{15}	Peak hour transportation time from town to Boston, 1970	-0.63803

Both the distance to Boston (X_{14}) and the peak-hour transportation time to Boston (X_{15}) are inversely related with accessibility. The distance of the town to the nearest cranberry market center (X_{12}) is also negatively related to accessibility. Since property tax tend to be higher in urban fringe areas, property tax rates based on real assessment (X_9) are expected to be positively related to the accessibility of an area.

Factor 4: Urbanism. While urbanization indicates a process of change, urbanism refers to the current characteristics of an area. There are three significant loadings for this factor, none of which are indicative of change. These significant loadings are:

X_5	Population density for town, 1970	0.92320
X_{19}	Percent of town in urban category, 1970	0.86750
X_9	Property tax per $1,000 real assessment for town, 1972	0.52333

The population density (X_5) and percent of the town area in the urban category (X_{19}) are both clearly indicative of urbanism. Property tax rates (X_9)

also tend to be higher in the more urban towns of the study area.

Factor 5: Ruralism. This factor has five significant factors, which are as follows:

X_6	Change in population density of town, 1960 to 1970	-0.72205
X_{17}	Median family income for town, 1970	-0.60620
X_{13}	Average annual wage for town, 1971	-0.54422
X_4	Change in town population, 1960 to 1970	-0.51770
X_7	Acres of land suitable for development within town	0.51174

Change in the population density (X_6), median family income (X_{17}), average annual wage (X_{13}) and change in town population (X_4) would all be expected to be negatively related to ruralism. The acres of land suitable for development (X_7) would be positively related to ruralism since much of the available land will not yet have been developed.

Only one variable (X_{11}) is not to be found significant under at least one of the factors. Therefore, this variable is dropped from further consideration.

Regression Analysis

In the preceding subsection of this report, an attempt was made to interpret the underlying interrelationships among the variables. Now, the task is to develop a projective model in which forecasting accuracy is the ultimate objective. Because of the nature of the data and the sampling technique employed, the traditional concepts of statistical significance are relegated to a minor and somewhat unclear role.

In order to utilize regression techniques as a projection tool, it is desirable to find a few independent variables that are strongly associated with the dependent variable. By assuming that these relationships will continue in

the future, projected figures for the number of acres of cranberry bogs can be developed. Therefor, a means was sought to obtain a regression equation having a high coefficient of determination (R^2) and including a relatively few variables so that projections could be more easily made.

The Maximum R^2 Improvement procedure developed by James H. Goodnight at North Carolina State University[1/] was utilized with X_1 (acres of cranberry bogs in town, 1973) the dependent variable and the fifteen other variables being independent. This technique retains the regression model with the highest coefficient of determination (R^2) for any given number of variables.

Use of the Maximum R^2 Improvement regression technique reveals a coefficient of determination of 0.984 for as few as five independent variables (Table 8). The estimating equation was:

$$Y = 63.41 + 0.781X_2 + 0.271X_6 - 1.370X_{12} - -0.015X_{20} - -0.027X_{23}$$

In this case, two variables, X_2 (acres of cranberry bogs in town, 1966) and X_6 (change in population density) are positively related to the dependent variable. The time period required to establish new cranberry bogs, four to five years, makes short-term fluctuations in acreage in response to yearly market conditions difficult. The marketing agreement also prevents the establishment of new bogs so future acreages can be expected to be closely related to the present magnitude. However, there does not seem to be any reasonable explanation as to the positive relationship between changes in the population density and cranberry acreage.

Three independent variables in this equation are inversely related to the town acreage of cranberry bogs. These are X_{12} (distance from town to nearest

1/ Service, Jolayne, A User's Guide to Statistical Analysis, Department of Statistics, North Carolina State Univ., Raleigh, N.C., Aug., 1972, p. 128.

Table 8. Coefficients and Computed T-Values for Equation I.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Acres of cranberry bogs in town, 1966	0.781	0.016	48.35
X_6	Change in population density of town, 1960 to 1970	0.271	0.091	2.974
X_{12}	Distance from center of town to nearest cranberry market center	-1.370	0.473	-2.898
X_{20}	Change in acreage of town in urban category, 1952 to 1972	-0.015	0.007	-1.992
X_{34}	Change in total housing units in town, 1960 to 1970	-0.027	-0.013	-2.062

$a = 63.410$ $R^2 = 0.984$

cranberry market center), X_{20} (change in acreage of urban lands in town), and X_{23} (change in total housing units). It is to be expected that the distance to the nearest cranberry market center would be negatively related to cranberry acreages. The inverse relationship between both X_{20} and X_{23} and acreage of cranberry bogs is to be expected. These are both indications of urbanization and, therefore, greater resource competition. Although its interpretation is somewhat unclear, as previously discussed, all of the variables included in this equation were significant at the $\alpha = .05$ level.

Reducing the number of independent variables to four resulted in a coefficient of determination decrease of only .002; two alternative equations giving equally good results (Tables 9 and 10). In both cases, variable X_2 is

Table 9. Coefficients and Computed T-Values for Equation II.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Acres of cranberry bogs in town, 1966	0.785	0.017	45.029
X_7	Acres of land suitable for development	0.002	0.007	1.483
X_{14}	Distance from town center to Boston	-0.870	0.291	-2.990
X_{23}	Change in total housing units in town, 1960 to 1970	-0.024	0.001	-3.468

a = 57.395 R^2 = .982

Table 10. Coefficients and Computed T-Values for Equation III.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Areas of cranberry bogs in town, 1966	0.788	0.017	47.154
X_{12}	Distance from center of town to nearest cranberry market center	-7.95	0.551	-1.443
X_{14}	Distance from town center to Boston	-0.624	0.330	-1.890
X_{20}	Change of acreage of town in urban category, 1952 to 1972	-0.018	0.006	-3.007

a = 78.345 R^2 = .982

retained. Variable X_{23} is also retained in Equation II whereas variables X_{12} and X_{20} remain in Equation III. Variable X_6 is not included in either of these equations. Those variables recurring in Equation II and III retained the same signs as in Equation I. With the exception of X_7 in Equation II and X_{12} in Equation III, all independent variables were significant of $\alpha = .06$.

Two new variables are found in Equation II. These were X_7 (Acres of land suitable for development) and X_{14} (distance from town to Boston), the latter also occuring in Equation III. The positive relationship between acres of cranberry bogs and acres of land suitable for development is to be expected. With a greater supply of suitable land, competition for acres used in cranberry production is apt to be less severe. Since competition for land and other resources would be greater in proximity to Boston, the economic and cultural center of the region, the negative relationship between X_{11} and the dependent variable requires further explanation. Within the limits of the data (i.e. the towns having cranberry bogs in 1966), the largest acreages are found in Plymouth County; those towns closer to Boston having very limited bogs. On the other hand, most towns outside of Plymouth County and more distant from Boston also tend to have lower cranberry bog acreages. In this case, it appears as though the inherent characteristics of Plymouth County which make it desirable for cranberry production have, thus far at least, more than offset the more severe resource competition that might be expected relative to more remote areas.

Equation IV contains only three independent variables but the coefficient of determination is still at a relatively high .981. The variables included in this equation are X_2, X_{14} and X_{20} (Table 11). Here again, X_2 is positively related to the dependent variable while X_{14} and X_{20} are inversely related to 1973 cranberry acreage. All three of the independent variables are significant at the $\alpha = .01$ level.

1 in Equation 1 among variables X_{11}

...tion I. Variable X_6 is not included in either of

the ... relation in Equation (2) and (3) remains ...

With the exception of X_6 in Equation (1) and (...

...ent variables were significant at .05.

...ent) and X_{11} (distance from ... Boston), the ...

Equation (1). The positive relationship between ... of

cranberry bogs and acres of land in cult... for cranberries ... is ... of

... a greater ... unity of suitable ... competition ... used of cranberry

production is ... to be less severe. Since competition ... in ... would

... would be greater in proximity to Boston, the ... of ...

... a region, the negative relationship between X_{11} and the ...

... needs further explanation. Within the limits of the ... the ...

... cranberry ... (as in 1966), the largest acreages are found in Plymouth County,

... towns ... Boston having very ... On the other hand,

... towns outside of Plymouth County and more distant ... Boston also tend

... have ... cranberry bog acreages. In this case, it appears as though the

... of Plymouth County ... make it desirable ... cranberry

... than ... can offset the ... severe ...

... be ... selected ... some areas.

Equation ... independent variables but the coefficient

... is ... The variables included in

X_{20} (... here again, X_5 is positively

... X_{21} ... related to

... dependent ...

Table 11. Coefficients and Computed T-Values for Equation IV.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Acres of cranberry bogs in town, 1966	0.797	0.016	51.333
X_{14}	Distance from town center in Boston	-0.848	-2.884	0.294
X_{20}	Change in acreage of town, in urban category, 1952 to 1972	-0.019	-3.105	0.006

$a = 66.071$ $R^2 = .981$

When reduced to two independent variables, the coefficient of determination declines only .003 (Table 12). The two variables in this equation are X_2 (acres of cranberry bogs in town, 1966) and X_{20} (change in acreage in urban category, 1952 to 1972). As has been the case in the equations previously discussed, X_2 is positively related to the dependent variable but X_{20} is inversely related. In equation V both independent variables are significant at the $\alpha = .01$ level.

The final equation to be considered from the maximum R^2 Improvement procedure contains only one independent variable (X_2), but has a coefficient of determination of .975. The equation takes the form of

$$Y = -3.139 + 0.789 X_2$$

with the variables as previously defined. This equation reemphasizes the strong relationship between cranberry bog acreages by town over time. The independent variable is significant at $\alpha = .0001$.

TABLE 12. Coefficients and Computed T-Values for Equation V.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Acres of cranberry bogs in town, 1966	0.780	0.017	48.020
X_{20}	Change in Acreage of town, in urban category, 1952 to 1972	-0.019	0.007	-2.887

a = 24.396 R^2 = .978

While the procedure employed to determine the equations previously described maximized the coefficient of determination for a given number of variables, it was deemed desirable to examine several other combinations of the variables for which projected data might be more readily accessible. If substitutes for variables for which it might be difficult to obtain projection data could be used, with only slight loses of effectiveness, the projection process would be enhanced.

Of the combinations of variables examined, those with the greatest promise involved the reintroduction of X_{12} (Distance from center of town to nearest cranberry market) into the multiple regression analysis. As might be expected, this variable is inversely related to town cranberry acreages. As the transportation costs of shipping cranberries from the bog to the reception point increases, bog acreages are expected to decrease.

Equation VII contains three independent variables; X_2, X_{12} and X_{20}. (Table 13) It is essentially the same as Equation IV, but with X_{12} replacing X_{14} (Distance from town center to Boston). Variable X_2 is positively related to the dependent variable whereas both X_{12} and X_{20} are negatively related. All three independent

variables are significant at the $\alpha = .01$ level. Both Equation IV and Equation VI have coefficients of determination of .981.

Finally Equation VIII is obtained by dropping X_{20} from Equation VII(Table 14). The resulting equation contains two variables (X_2 and X_{12}); both of which have readily available data for projection purposes. The coefficient of determination for this equation is .978, the same as Equation V after rounding. Equation V has the highest coefficient of determination for two independent variables as selected by the maximum R^2 improvement procedure. Therefore, without any measurable decrease in this coefficient, it is possible to project with readily accessible data. In this case as in the past, X_2 is positively related and X_{12} negatively related to the dependent variable. Both independent variables are significant at the $\alpha = .01$ level.

CRANBERRY PROJECTIONS

Time Series

While the danger of extending regression equations beyond the scope of the data is recognized, the use of these estimators to extrapolate provides an efficient means to project future events. As with any projections, they are expected to materialize only if their underlying assumptions accurately reflect future conditions. In this case, a paramount assumption is that the same relationships between the dependent and independent variables continue throughout the projection period.

By extrapolating the linear regression equation based on time series data for number of acres of cranberry bogs ($Y = 235.8 - 1.8t$) to 1990, the projected acreage is 7,120. Compared to the 1972 acreage of 10,900[1/] this represents a 35 percent decrease.

1/ This figure is based on estimates made by the New England Crop Reporting Service, United States Department of Agriculture, Statistical Reporting Service, Boston, Massachusetts. Actual acreage measurements made by the Cranberry Marketing Committee, Wareham, Massachusetts, indicated 11,266 acres of cranberry bogs in 1973 so the 1972 estimate may be slightly low.

Table 13: Coefficients and Computed T-Values for Equation VII.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Acres of cranberry bogs 1966	0.782	0.017	46.586
X_{12}	Distance from Center of town to nearest cranberry market center	-1.285	-0.498	-2.582
X_{20}	Change in acreage of town in urban category, 1952 to 1972	-0.018	0.006	-2.853

a = 62.082 R^2 = .981

Table 14: Coefficients and Computed T-Values for Equation VIII.

Variable Number	Variable Description	Regression Coefficient	Standard Error of Regression Coefficient	Computed T-Value
X_2	Acres of Cranberry bogs, 1966	0.773	0.018	43.836
X_{12}	Distance from center of town to nearest cranberry market center	-1.384	0.530	-2.614

a = 39.210 R^2 = .978

Extrapolation of the curvilinear regression equation ($\log Y = 4.97799 - 0.01459t$) for the same time series data indicates 7,982 acres of cranberry bogs by 1990, a 27 percent decrease. These 1990 acreage projections are remarkedly close considering the length of the projection period and the limited time series used.

The projections of cranberry yield per acre were far more diverse than the projections of total bog acreage. Extrapolation of the linear equation ($Y = 32.0 + 2.1t$) indicated an average yield of 116 barrels of cranberries per acre by 1990 as compared to the present yield of under 100 barrels per acre. By contrast, the curvilinear estimating equation indicated an average yield of 159 barrels per acre.

Multiple Regression

At this stage of the Massachusetts Water Resources Study, the selection of the multiple regression equation to be used to extrapolate future acreages is limited by data availability. No projections of the socioeconomic variables most closely related to cranberry bog acreages are available although it is anticipated that they will be before the completion of the study. As a result, Equation VIII was chosen to project 1980 and 1990 cranberry acreages. As previously indicated, this equation took the form

$$Y = 39.210 + 0.773 X_2 - 1.384 X_{12}$$

where Y is the acres of cranberry bogs for a town at a given point in time

X_2 is acres of cranberry bogs for that town seven years previously and

X_{12} is the distance from center of the town to the nearest cranberry market center

The appropriate data was substituted into this equation and it was operated

recursively for each town to obtain projections for 1980 and 1990. These town projections were aggregated into watershed planning areas to provide the information in the form most useful for the study.

The projections of cranberry bog acreages determined by this methodology were somewhat lower than those determined strictly by the extrapolation of time series information (Table 15). Total cranberry acreages for the region were projected to be 8,830 acres for 1980 and 6,300 for 1990. This compares with projections in excess of 7,000 acres for 1990 determined by extrapolating either the linear or curvilinear equations for the time series data.

These projections indicate that Buzzard's Bay will continue to lead the other Watershed Planning areas in acres of cranberry bogs through 1980 and 1990 and will retain about the same proportion of the region's total acreage. Cranberry acreages are projected to decline relatively least rapidly in the Taunton Planning area and most rapidly on Cape Cod and the Islands.

Table 15 - Current and projected acres of cranberry bogs by watershed planning areas

Watershed Planning Area	Acres of Cranberry Bogs					
	1973	Percent of Total	1980	Percent of Total	1990	Percent of Total
Buzzard's Bay	5,431	48.2	4,280	48.5	3,080	48.9
South Shore	2,159	19.2	1,700	19.3	1,240	19.7
Taunton	2,097	18.6	1,810	20.4	1,500	23.8
Cape Cod & Islands	1,468	13.0	1,000	11.3	460	7.3
Other	111	1.0	40	0.5	20	0.3
Total	11,266	100.0	8,830	100.0	6,300	100.0

ESTIMATED WATER USE

Having projected future cranberry acreages by watershed planning areas, the task was to estimate the quantity of water that would be used to carry on the various cultural practices employed in cranberry production if water availability was not a factor. In order to facilitate this, the following assumptions were made:

(1) The average cranberry bog is currently about one-and-a-half feet out of grade.1/ It is assumed that additional diking and the abandonment of many bogs seriously out of grade will cause this average to drop to about one foot by 1990. As a result, the average quantity of water needed to flood bogs for various purposes will decline proportionately as bogs become more level.

(2) Winter flooding will take place on all bogs. Current estimates indicate this requires 1,225,000 gallons of water per acre.1/

(3) Spring reflow will be utilized on about eight percent of the total bog acreage. Where frost protection is available, spring reflow is used only for special purposes such as certain types of insect and weed control. It is not anticipated that this proportion of the total acreage will change significantly over the projection period. Spring reflow presently requires about 725,000 gallons per acre.1/

(4) About three-fourths of the cranberry acreage in the region has sprinkler systems to provide frost protection. Since most of the acreage not so protected have especially good water facilities to provide flood protection, the rate of adoption of sprinkler systems is expected to stabilize. Thus, about 80 percent of the acreage will be protected by sprinkler systems by 1980 and 85 percent by 1990. Flood protection will be used for the residual acreage in each case. Estimates for water use to provide sprinkler

---

1/ Information obtained from the Cranberry Experiment Station, East Wareham, Massachusetts.

[illegible] the quantity of [illegible]

[illegible] sprinkler systems [illegible]

[illegible]

[illegible]

[illegible] (2) [illegible]

[illegible]

(3) [illegible]

[illegible] only

[illegible]

[illegible]

[illegible] 100 gallons per acre.

[illegible] the cranberry growers in the region [illegible]

[illegible] to provide [illegible] Since most of the areas [illegible]

[illegible] especially [illegible]

[illegible] of sprinkler systems [illegible] expected [illegible]

[illegible] of the acreage will be protected by sprinkler systems

[illegible] protection will be used [illegible]

[illegible] of water use [illegible]

frost protection, both spring and fall, are 135,770 gallons per acre. This is contrasted with flooding which presently requires approximately 2,500,000 gallons per acre for spring frost protection and 1,150,000 gallons per acre for fall protection.1/

(5) Water harvesting presently occurs on about one-third of the total cranberry acreage. This method of harvest grew rapidly during the period when market allotments, which were based on production, were being established by the individual growers. Even with premiums paid for dry harvesting, it is expected that labor shortages for harvesting as well as greater yields will induce more growers to turn to water harvesting. A greater rate of attrition is also expected for bogs which are not adapted to water harvesting. As a result, it is anticipated that water harvesting will increase to one-half of all cranberry acreage by 1980 and then stabilize. It is estimated that water harvest floods require about 625,000 gallons per acre.1/

(6) Trash floods are generally necessary on those bogs that have not been water harvested. This requires about 825,000 gallons per acre.1/

For the region, the total quantity of water that would be required to apply the previously described cultural practices on future acreages is projected to decrease 59 percent by 1990 (Table 16). While these projections indicate a decline in water use in all watershed planning areas, the decrease is proportionately least in the Taunton Planning Area and proportionately greatest in Cape Cod and the Islands.

Much of this decrease can be attributed to the projected reduction in the acreage in cranberry bogs but the average quantity of water used per acre is also expected to decrease. Since substantially more water is required to flood bogs which are seriously out of grade, the abandonment or diking of such bogs will reduce the quantity of water needed. The quantity of water

---

1/ Information obtained from the Cranberry Experiment Station, East Wareham, Massachusetts.

used for frost protection purposes is also expected to decrease as more low gallonage sprinkler systems are installed. Although a greater proportion of cranberry bogs are expected to be water harvested in the future, this is not likely to require additional water since this method of harvest eliminates the need for trash floods.

It should be emphasized that these estimates reflect the quantity of water that is needed to effectively employ the cultural practices previously described, and do not indicate actual water use. The quantity of water used in cranberry culture is dependent upon its availability as well as other factors. Current estimates of needs are likely to exceed use, but as the bogs with poorer water supplies are abandoned over time, it is expected that the projected quantity of water needed for these cultural measures will approximate use.

Table 16-- Estimated water requirements to apply designated cultural practices by watershed planning areas, current and projected.

Watershed Planning Area	Millions of Gallons of Water Used		
	1973	1980	1990
Buzzard's Bay	15,515	10,507	6,522
South Shore	6,168	4,174	2,625
Taunton	5,990	4,444	3,117
Cape Cod & the Islands	4,194	2,455	975
Other	318	99	43
Total	32,185	21,679	13,282

SUMMARY AND CONCLUSIONS

Although agriculture is a minor component of the Massachusetts economy, southeastern Massachusetts is the leading cranberry producing area in the Nation. This is an important consideration for water resource planners of the region since water management is an integral part of cranberry culture.

Water is used for many purposes in the growing of cranberries. The cranberry bogs are flooded during the winter to protect them from "winterkill" caused by desiccation. After the bogs are drained in the spring, they are often refilled for a period of several weeks to protect the vines from frost and several other purposes. Water is used for frost protection in both the Spring and Fall by use of several techniques. The bogs can be flooded for this purpose, but more recently growers have relied to a greater degree on sprinkler systems to provide frost protection. Cranberry bogs are also flooded so that water harvesting can take place. After dry harvesting, bogs are usually flooded so that debris may float to the surface and be skimmed off. During periods of dry weather, bogs are also irrigated.

While Massachusetts has long been the leading cranberry producing state in the Nation, its proportion of total production has been declining in recent years. This has been caused by more rapid increases in production in other areas since production has also been generally increasing in Massachusetts. Increased production can be attributed to greater yields per unit of area, as total acreage hasn't changed much in recent years. Of the watershed planning areas containing commercial cranberry bogs, Buzzards Bay leads in acreage with nearly one-half of the region's total. However, both the Taunton and South Shore Planning areas have relatively large acreages of cranberry bogs. Cape Cod and the Islands, once the leading cranberry producing area, presently

has less than 1,500 acres of commercial bogs.

Other trends have also been noticeable in the cranberry industry. There has been a tendency toward fewer but larger producers as has been the case for much of agriculture in the New England area. Sprinkler systems have become prevalent in recent years and now are used on about three-fourths of the total cranberry bog acreage. Water harvesting has also increased considerably in recent years.

Cranberries are produced for two rather distinct markets; one for fresh fruit and the other for processing. In recent years, nearly 70 percent of the marketed crop in Massachusetts was sold for processing. Water harvesting, which produces greater yields, may be used for berries to be processed but not for fresh fruit, due to rapid deterioration, in this region. Premiums are usually paid for dry harvested fruit. Most cranberries produced in southeastern Massachusetts are sent to processing plants located within the area.

A marketing order and agreement to limit cranberry production was passed by growers across the nation in 1968. Individuals marketing quotas are established on the basis of the growers best two crop years between 1968 and 1973.

Regression analysis techniques are used on cranberry acreage and yield per acre using 1950 to 1972 data. Extrapolation of the regression equations so developed indicate 7,120 acres of commercial cranberry bogs for 1990 by the linear equation and 7,982 acres by the curvilinear equation. Cranberry yieldsper acre for 1990 are 116 and 159 respectively for the linear and curvilinear estimating equations.

In order to gain a better insight into the interrelationships between cranberry bog acreages and selected socioeconomic and locational variables, multivariate statistical techniques are employed. Initially, twenty-three town

variables are selected for study but six of these are eliminated because they are highly intercorrelated with other variables. The factor analysis technique is utilized on the remaining variables in order to identify underlying interrelationships and to eliminate other variables if they are not closely related to any of the extracted factors. A maximum R^2 improvement procedure for multiple regression analysis is employed on the remaining variables to determine the highest possible coëfficient of determination for a given number of variables. Several other multiple regression equations are also determined using other combinations of variables.

Five orthogonal factors are extracted from the seventeen variables through the factor rotating procedure. These were identified as urbanization, cranberry industry viability, accessibility, urbanism, and ruralism.

The maximum R^2 improvement regression technique reveals a coefficient of determination of .984 for as few as five independent variables. Eight multiple regression equations are developed to provide a basis to project future cranberry acreages by town.

Due to the inavailability of certain projected data at this stage of the study, a number of equations cannot yet be effectively used for projection purposes. The equation used to project future cranberry acreages by town and provide the basis to aggregate this information into watershed planning areas is

$$Y = 39.210 + 0.773X_2 - 1.384\ X_{12}$$

where

Y = is the town acreages of cranberry bog for a given year

X_2 is acres of cranberry bogs in the town seven years previously

and

X_{12} is the distance from the center of the town to the nearest cranberry market center

Using the above equation, the projected cranberry acreage in southeastern Massachusetts for 1990 is 6,300 acres. Of the watershed planning areas, Buzzards Bay continues to lead with almost one-half of the regional total but the Taunton and South Shore both continue to have sizeable acreages. On the basis of these acreages and other assumptions, the total quantity of water used for the growing of cranberries in 1990 will be 13,282 million gallons, less than one-half of the current estimate.

APPENDIX A. Towns included in Designated Planning Areas.

Buzzards Bay Study Area

Acushnet	Mattapoisett
Carver	New Bedford
Dartmouth	Rochester
Fairhaven	Wareham
Fall River	Westport
Marion	

South Shore Study Area

Braintree	Norwell
Cohasset	Pembroke
Duxbury	Plymouth
Hanover	Quincy
Hingham	Randolph
Holbrook	Rockland
Hull	Scituate
Kingston	Weymouth
Marshfield	

Taunton Study Area

Abington	Hanson
Avon	Lakeville
Berkley	Mansfield
Bridgewater	Middleborough
Brockton	Norton
Dighton	Plympton
East Bridgewater	Raynham
Easton	Stoughton
Foxborough	Taunton
Freetown	West Bridgewater
Halifax	Whitman

CAPE COD AND ISLANDS AREA

Barnstable	Mashpee	Chilmark
Bourne	Orleans	Edgartown
Brewster	Provincetown	Gay Head
Chatham	Sandwich	Gosnold
Dennis	Truro	Nantucket
Eastham	Wellfleet	Oak Bluffs
Falmouth	Yarmouth	Tisbury
Harwich		West Tisbury